A comparison of the minimum canal wall thickness remaining following preparation using two nickel–titanium rotary systems

M. Garala, S. Kuttler, P. Hardigan, R. Steiner-Carmi & S. Dorn
Department of Postgraduate Endodontics, College of Dental Medicine, Nova Southeastern University, Ft. Lauderdale, FL, USA

Abstract

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Aim To examine *in vitro* whether Profile or Hero 642 nickel–titanium rotary instrument systems substantially reduce the minimum canal wall thickness present following root-canal preparation.

Methodology The canal anatomy of 26 mesial roots from mandibular molars with separate buccal and lingual canals was evaluated before and after instrumentation using the Endodontic Cube. Following access, working lengths were determined and then samples invested within the cube using acrylic resin. Canal cross-sections were subsequently prepared. Samples were then instrumented within the cube and pre- and post-instrumentation images of the sections were compared to determine the minimum canal wall thickness remaining after preparation.

Results Buccal and lingual canals within the sections from each level (coronal to apical) showed a reduction in minimum canal wall thickness after instrumentation. No statistically significant differences in canal wall thickness were found between the two systems at any level of the root.

Conclusions Instrumentation with either of the two systems under investigation did not compromise canal wall thickness. Pre-operative canal wall thickness was found to be the most significant factor determining the minimum canal wall thickness after preparation.

Keywords: canal wall thickness, Endodontic Cube, nickel–titanium.

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Introduction

Primary objectives of canal preparation include the removal of organic substrate from the canal system by chemo-mechanical methods, and the three-dimensional shaping of the root-canal system into a continuously tapering preparation while maintaining the original outline form of the canal (Schilder 1974).

These objectives are often difficult to achieve because of variations in canal cross-sectional shape (Kerekes & Tronstad 1977), presence of anatomical irregularities and canal curvature, which often occurs in more than one direction. Stainless steel instruments possess reduced flexibility in larger sizes and tend to straighten in curved canals. This results in an increased incidence of procedural errors such as ledge, zip, elbow formation, canal transportation (Weine *et al.* 1975) and stripping (Abou-Rass *et al.* 1980). The problems associated with stainless steel hand instruments are compounded when applied in rotary systems (Mizrahi *et al.* 1975).

The introduction of Nitinol to endodontics (Walia *et al.* 1988) provided a material with superior flexibility and resistance to torsional fracture. These properties enabled improved design features, which reduce procedural errors and result in canal preparations that maintain the original canal form when either rotary or hand instrumentation is employed (Esposito & Cunningham 1995, Short *et al.* 1997).

The shaping ability of Profile and Hero 642 rotary instruments have been investigated using a number of experimental models, including simulated canals

Correspondence: Dr Manish Garala, Department of Endodontics, NSU-CDM 3200 S, University Drive, Ft. Lauderdale, FL 33328, USA (Tel.: +1 954 262 7336; fax: +1 954 262 1782; e-mail: mgarala@yahoo.com).

(Thompson & Dummer 1997) and extracted teeth (Ottosen *et al.* 1999, Hülsmann *et al.* 2001).

A substantial number of these and other reports (Bryant & Dummer 1998, Ahlquist *et al.* 2001) have evaluated the Profile rotary system (Maillefer, Ballaigues, Switzerland) but relatively few (Thompson & Dummer 2000, Hülsmann *et al.* 2001) have observed the performance of the HERO 642 system (Micromega, Besancon, France).

The purpose of the study was to compare the effects of the Profile system with the Hero 642 system for minimum canal wall thickness remaining in mesial roots of mandibular molars, using the Endodontic Cube as the experimental model (Kuttler *et al.* 2001).

Materials and methods

Mesial roots of 26 mandibular first and second molars demonstrating a type IV canal configuration (Vertucci 1984) were selected. The type IV canal configuration consists of roots with two separate canals and two separate apical foramina. These samples were then placed in 5.25% sodium hypochlorite for 15 min for disinfection and then stored in normal saline with 0.1% thymol to inhibit bacterial growth. The distal root was removed from the samples by sectioning 1 mm below the furcation using a Carborundum disc of 0.8 mm thickness and 22 mm diameter (Jelenko Dental Health Products, Armon, NY, USA).

Mesial–distal and buccal–lingual radiographs were taken using a digital imaging system (Schick Technologies Inc., Long Island City, NY, USA), with the cone at a fixed distance of 15 cm from the sample.

Standard access cavities were prepared with 1558 and 1958 crosscut fissure burs (Brasseler, USA, Savannah, GA, USA) in a high-speed handpiece. Access was refined using round burs (Brasseler USA) within the chamber to obtain straight-line access to the mesial–lingual and mesial–buccal canal orifices. To determine working length, a size 15 K-Flex file (Kerr Corporation, West Collins, CA, USA) was placed inside the canal until its tip was just visible at the apical foramen when examined using an operating microscope at 9× magnification (Global Protégé plus, Global Surgical Corporation, St. Louis, MO, USA). The final working length was calculated using a digital radiograph of the instruments in this position and then subtracting 1 mm. Screen images of samples displaying curvature less than 10° in a mesial–distal direction according to Schneider's method (1971) were excluded.

A cotton pellet and wax was used to seal the access cavities to prevent ingress of acrylic resin when embedding the tooth within the Endodontic Cube. Each tooth was immersed in methylene blue dye (To Dye For, Roydent Dental Products, Rochester Hills, MI, USA) for a period of approximately 10 s. This provided a clearer demarcation of the root outline when sectioned, allowing more accurate measurements without changing the physical properties of the tooth. The Endodontic Cube was then assembled using the external fixation screws (Kuttler *et al.* 2001). The assembled cube was placed on a laboratory vibrator and was filled with acrylic resin (Integrity, Dentsply Caulk, Milford, DE, USA). Samples were embedded within their respective cubes and cured under vacuum conditions of 20 psi for 15 min. Excess material around the exposed access cavity was removed and the cubes were disassembled.

Using horizontally registering projections present on opposite walls of the sample as a guide, transverse sections were prepared in a coronal to apical direction from the furcation at 2 mm intervals using a diamond disc (15HC, Buehler Ltd, Evanston, IL, USA) in an Isomet low speed sectioning machine (Buehler Ltd). The sections obtained for each tooth were labelled to indicate the section number within each sample. Locating marks were placed on each section to enable overlap of pre- and post-instrumentation images and to identify buccal or lingual canals within the section at the time of evaluation. Using a specially constructed jig to maintain reproducibility, the sections were imaged digitally using a high-resolution digital camera (Coolpix 990, Nikon, Melville, NY, USA) mounted on a microscope (Global Surgical Corporation) at 14× magnification. Microscope and camera settings were recorded to enable accurate superimposition of pre- and post-instrumentation images.

The Endodontic Cube was reassembled and instrumentation carried out using water as an irrigant and RC prep (Premier Dental Products, King of Prussia, PA, USA) as a lubricant. An equal number of buccal and lingual canals were instrumented with each system to account for possible variations in canal anatomy. The buccal canal for the first sample was randomly designated for instrumentation using the Profile system, and the lingual canal in this sample was then instrumented solely using the Hero 642 system. For the next sample, Hero 642 was used exclusively for the buccal canal and Profile for the lingual canal, with this alternate sequencing of systems then used for the remainder of the samples. The operator ensured strict adherence to the manufacturer's protocols in order to eliminate possible variables from different preparation techniques.

Profile and Hero 642 instruments were used in a TCM electric handpiece (Nouvag, Goldach, Switzerland) within the recommended range at 300 r.p.m. Torque levels were fixed at 8 N cm^{-1} by the unit. Canals were irrigated with tap water after every third instrument and given a final flush irrigation with 5.25% sodium hypochlorite. This procedure was repeated for the buccal and lingual canals of all samples. Instruments from each system were used for the preparation of five canals and then discarded.

After the canal had been negotiated to working length using a size 15 K-Flex file instrumentation using the Profile system began with the use of orifice openers 0.06 taper and ISO size 40 and 30 in the coronal third of the canal. Using a crown-down technique, 0.06 taper sizes 25 and 20 files were used sequentially for preparation to working length or within 2–3 mm of working length. In more than 60% of canals, a 0.06 size 20 was the first file to reach working length. Instruments with 0.04 taper of sizes 20, 25 and 30 were then used sequentially until a final preparation size of 30 0.04 at working length was obtained. These instruments were used passively without excessive apical force until resistance was met.

The Hero 642 protocol provided more specific guidelines for use stating that 0.06 taper sizes 30, 25 or 20 instruments were not to penetrate further than 1/3–2/3 of working length. The 0.04 taper sizes 30, 25 or 20 instruments were to remain 2–3 mm short of working length, and the 0.02 taper sizes 30, 25 and 20 instruments were to be used to prepare to full working length. This usually resulted in the coronal preparation being carried out using a 0.06 taper size 30 instrument, and a 0.04 size 30 to within 2–3 mm of working length. Sizes 25 or 20 instruments of 0.06 or 0.04 taper were not required in 35% of cases for coronal or mid root preparation as they did not encounter any resistance after a size 30 had been used for preparation. Where the penetration lengths stated could not be achieved using size 30 instruments of the designated taper, sizes 25 and 20 were then used. Sizes 25 and 30 0.02 instruments were used to complete apical preparation.

Canal preparation using either system was considered complete when a size 30 instrument of the manufacturer's recommended taper could be introduced passively to working length. This represented a size 30 0.04 for the Profile system and 30 0.02 for the Hero 642 system.

The cubes were disassembled, sections removed and post-instrumentation digital images obtained using an identical method to that used for preinstrumentation images. Digital images obtained were transferred to a computer and analysed using the ADOBE PHOTOSHOP 5.5 software program (Adobe Systems Inc., Mountain View, CA, USA). Pre- and post-instrumentation images were evaluated to determine the minimum canal wall thickness from all directions. This was determined by superimposing pre- and post-instrumentation images and measuring distances from the external aspect of the canal to the external aspect of the root. The shortest distance was selected from these values as the minimum canal wall thickness present before and after instrumentation. Based on the difference in these measurements, a value in millimetres for the amount of canal wall removed in this plane during preparation was also obtained.

Mean values for minimum canal wall thickness and canal wall removed at each level of sectioning were determined separately for buccal and lingual canals prepared by each instrument system, initially creating four groups of results.

A statistical software package (SPSS v. 10.0; SPSS Inc., Chicago, IL, USA) was employed to determine whether any differences in the measurements obtained between instrument systems were statistically significant. Specifically, the General Linear Model (GLM) for univariate analysis was used to evaluate the influence of the instrument systems on minimum canal wall thickness at each level of investigation. Statistical significance values were set at $P = 0.05$. A null hypothesis of there being no significant difference in minimum remaining canal wall thickness and amount of canal wall removed when comparing the two instrument systems was accepted or rejected.

Results

Two samples were discarded owing to an inability to renegotiate canals to original working length using size 15 K-Flex files. Four to five cross-sections were obtained from each of the remaining 24 samples. Mean values of 21.5° and 22° were obtained for curvature of buccal and lingual canals, respectively (range: 10–35°). Using paired *t*-tests, no statistical differences in curvature were found between buccal and lingual canals, or between canals assigned to each of the instrument systems. This confirmed that groups were balanced with respect to angle of curvature.

For each system, mean values for minimum canal wall thickness before and after preparation were calculated from all sections at the same level in the root. No significant differences in canal wall thickness were found between buccal and lingual canals at any level pre- or post-instrumentation. This enabled data from both

Table 1 Measurements for minimum canal wall thickness present before and after canal preparation

Section level (coronal–apical)	Profile (mm)				Micromega (mm)			
	Pre-thickness		Post-thickness		Pre-thickness		Post-thickness	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	1.66	0.45	1.43	0.54	1.65	0.64	1.39	0.62
2	1.27	0.27	1.07	0.3	1.27	0.29	1	0.33
3	1.27	0.24	1.11	0.27	1.2	0.27	1.01	0.3
4	1.29	0.24	1.14	0.23	1.25	0.29	1.13	0.29
5	1.15	0.29	1.09	0.33	1.16	0.33	1.09	0.37

Table 2 Mean values for canal wall thickness removed at each level of sectioning

Section level (coronal–apical)	Profile (mm)		Micromega (mm)	
	Mean	SD	Mean	SD
1	0.2	0.15	0.26	0.2
2	0.2	0.14	0.26	0.19
3	0.16	0.11	0.14	0.1
4	0.15	0.12	0.11	0.11
5	0.08	0.05	0.07	0.07

canals to be combined for each instrument system, reducing results groups from four to two (Table 1).

It was determined that there were significant differences initially in minimum canal wall thickness with a greater thickness present for the coronal-most section in comparison to the four apical-most sections ($P = 0.0001$). No further differences were found between mid-root and apical sections. All post-instrumentation measurements showed reductions in minimum canal wall thickness, but no further statistically significant differences were found after instrumentation with either system. Significant differences in canal wall thickness found before preparation were reproduced in the post-instrumentation analysis.

Canal wall thickness removed was significantly less when comparing the apical-most sample (section 5) with all other section levels, and between sections four and two, and four and one (Table 2). Therefore, even though statistically significant differences in remaining canal wall thickness were not present owing to either instrument system, significantly less canal wall structure was removed by both systems in apical sections compared to coronal sections.

Seventy-three sections from a total of 184 had less than 1 mm of minimum canal wall thickness remaining post-instrumentation (Table 3). Forty-nine per cent of these samples had a canal wall thickness of less than 1 mm prior to preparation. Canal wall thickness removed during preparation was never greater than 60% indicating that the canal wall was initially thin in these samples. Furthermore, only three sections had a remaining minimum thickness of less than 0.5 mm.

Discussion

Limitations of this study included obtaining only 12 sections for the Profile group and 14 sections for the Hero 642 group at the apical-most level (section 5). This is in comparison to sections 2–4 where there were an average of 23 sections for each group. This occurred owing to difficulties in determining the precise location of the cut for the final section. It is also difficult to process the apical-most section as it was invariably the smallest and possessed the least retention when embedded within the acrylic resin. When using this technique in the future, this limitation will be overcome using methods that are currently being tested in other studies. Another possible limitation was the subjective assessment of

Table 3 Sections with less than 1 mm of minimum canal wall thickness before and after preparation

Section level (coronal–apical)	Profile			Micromega		
	<1 mm pre-op	<1 mm post-op	Lowest value (mm)	<1 mm pre-op	<1 mm post-op	Lowest value (mm)
1	–	4	0.76	–	3	0.71
2	7	11	0.53	7	13	0.35
3	4	8	0.77	7	8	0.48
4	2	6	0.78	3	9	0.63
5	4	6	0.37	2	5	0.50

reference points for canal wall thickness measurements. This was minimized by the section being magnified by 14× during image capture and further magnified by computer during image analysis. The outline of the external canal wall was stained in order to provide a more clear distinction from the acrylic resin.

Numerous variables required consideration when designing this study and attempts were made to control for their effects. Both groups were balanced for number of samples, and the instruments were used alternately in buccal and lingual canals of consecutive samples to compensate for possible differences in canal morphology. Statistically significant differences in degree of canal curvature were not found between groups. The operator was not experienced with either system under investigation. The General Linear Model of univariate analysis (SPSS, 2000) was chosen, as it allows the effects of a number of factors on the minimum canal wall thickness to be analysed. It enables the determination of whether a single factor has a significant effect by itself, or if the interactions of a number of factors significantly affect the minimum canal wall thickness. This reduced the likelihood of committing errors when determining hypothesis validity.

The most important feature of analysing canal preparation by this technique is the ability to directly compare pre- and post-instrumentation canal anatomy. This enables each uninstrumented section to serve as a control for the post-instrumentation section. The Endodontic Cube is an extensively redesigned version of the method for canal anatomy evaluation developed by Bramante *et al.* (1987), and was constructed because of potential limitations identified in existing systems. Bramante *et al.* (1987) and others (Leseburg & Montgomery 1991, Glosson *et al.* 1995) used plaster for the external model to support and hold the sections in place. It is questionable whether the sections would be held together without movement, as plaster is brittle and subject to wear through friction. Experimental errors could be introduced if the sections are not maintained in their correct spatial relation because the original canal outline will not be reproduced. The Endodontic Cube is assembled from five brass alloy sections secured by screws, to provide rigid fixation for the canal cross-sections of each sample. It has external markings to provide ease of assembly. Once it has been assembled, it can be used as a rigid support to invest the tooth in resin, and can be used to produce as many samples as required. Some existing designs require the individual construction of external models to support each sample (Bramante *et al.* 1987, McCann *et al.* 1990). The cube can also be partly disassembled allowing radiographs of the sample to be taken. The internal walls have machined grooves at 2-mm intervals, which increase resistance of sections to displacement during use, and provide references for accurate sectioning of samples. These features ensure that sections are always correctly oriented with respect to one another, allowing the accurate reproduction of the unsectioned canal profile. The unimpeded passage of instruments during canal preparation is critical to obtain valid results.

Other techniques to evaluate changes in root canal anatomy after preparation are unable to accurately provide such extensive information for quantitative analysis. Radiographic assessment does not allow three-dimensional analysis which is critical when attempting to determine the minimum canal wall thickness (Goldman *et al.* 1974). Scanning electron microscopy does not allow the comparison of pre- and post- instrumentation features, and replication of internal canal anatomy using materials for creating canal impressions or models are highly technique sensitive (Goldman *et al.* 1989). Evaluation of root canal sections is possible using computed tomography (CT) or microCT, but is time consuming (Peters *et al.* 2001). Furthermore, once the sections have been obtained they still require evaluation using image analysis software.

The results obtained in this study indicate that the minimum remaining canal wall thickness is not significantly altered by either instrument system at any location of the root based on the sections evaluated. There were no statistically significant differences in minimum canal wall thickness between buccal and lingual canals before or after preparation. This indicates that variations in buccal and lingual canal morphology are not influential factors for this parameter. It is possible that differing radii of curvature and differing canal diameters may influence instrument performance.

Evaluation of preinstrumentation sections indicated significant differences in mean values for minimum canal wall thickness between the coronal-most section and all other more apical sections. This appears valid because the coronal-most section is just below the level of the furcation, where the greatest amount of dentine and cementum should be present in accordance with the tapering anatomy of the root. The direction of measurements obtained for minimum canal wall thickness was always towards the distal wall of the mesial canals, and is attributed to the concavity present on the distal wall of the mesial root.

Post-instrumentation analysis showed no further differences in minimum canal wall thickness implying no

substantial reduction by either of the instrument systems. Preinstrumentation canal wall thickness appears to be the most significant factor in determining post-instrumentation canal wall thickness.

Neither system used for canal instrumentation appear to over-prepare the canals or compromise the integrity of the root by excessive removal of the canal wall. This is in agreement with studies by McCann *et al.* (1990) who found that canal thickness remaining following preparation was not significantly affected by the instrument or instrumentation technique that was used. According to Lim & Stock (1987), an arbitrary value of 0.3 mm of dentine has been designated as the minimum canal wall thickness that should remain after preparation. This is to provide sufficient resistance to obturation forces and to forces exerted during function. Dentine contributes to the structure of the root canal wall more than cementum and it is questionable whether less than 0.3 mm of dentine is present in even the thinnest of sections. Caputo & Standlee (1976) determined that 1 mm of tooth structure was required around a post to significantly increase root fracture resistance. Following preparation, 60% of sections had a mean value of greater than 1 mm for the remaining canal wall thickness. However, following post preparation, this may become less than the 1 mm required.

From the 184 buccal and lingual canal sections evaluated, 29 had greater than 25% of their original canal wall thickness removed by instrumentation, but only one canal section had greater than 55% removed. This section still had more than 1 mm of canal wall thickness remaining. This is in contrast to the study by McCann *et al.* (1990), where even though ultrasonic and hand instrumentation reduced canal wall thickness only by an average of 18 and 25%, respectively, 42% of the hand-file-prepared samples had less than 0.5 mm of wall thickness remaining, and 33% of ultrasonically prepared samples had less than 0.5 mm remaining. This may be because of possible differences in sample population or method of measurement, as McCann *et al.* (1990) found that the mean preinstrumentation values for canal wall thickness were less than 1 mm for all sections except those taken at the level of the furcation.

The highest standard deviation value obtained for canal wall thickness measurements was 54.1% of the mean value. Even though this value is mathematically high, previous studies assessing remaining canal wall thickness have reported standard deviation values as large as 60% of the mean value (McCann *et al.* 1990). This is probably owing to anatomic variations in natural cementum/dentine thickness occurring at different apical–coronal levels of the tooth and between individual tooth samples.

It was interesting to note that the apical sections underwent the least preparation as shown by the significantly higher amounts of canal wall thickness removed in more coronal samples (Table 2). Many apical and coronal preparations were seen where only part of the canal was instrumented. Chemo-mechanical debridement is critical to remove inflamed tissue, bacteria and their toxins, and without adequate canal preparation prognosis is likely to be compromised. As the post-instrumentation minimum canal wall thickness present was not significantly reduced, further enlargement may be appropriate to incorporate a greater area of the original canal within the preparation.

Conclusions

In conclusion, it appears that neither of the nickel–titanium systems investigated in this study significantly reduces canal wall thickness in mesial roots of mandibular molars.

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